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Relationship of Xylary Cell Structure to Sap Movement in Engelmann Spruce

ABSTRACT

The amount of sap movement in Engelmann spruce is shown by sap velocity profiles. These profiles indicate little sap flow in the outer 5 mm of the secondary xylem of the living tree. Sap flow is maximum at 15-20 mm into the sapwood and levels off at 30-35 mm.

Microscope observations were made on samples taken at various radial depths from the cambium at breast height of the tree. The variances within the sap velocity profiles were correlated with an anatomical characteristic of the sapwood; the cross-sectional area of the cell lumen. The study of the woody plant tissues was accomplished by extracting core samples from living trees instrumented electrically to measure the sap flow by the heat-pulse technique. These samples were collected at one-month intervals (May through August, 1967) from the instrumented trees located on the Fraser Experimental Forest at Fraser, Colorado. Growth rings were counted and related to radial depths within the tree. The wood cores were then divided into 5 mm blocks for specific study of the cross section.

Tissues were sectioned with a sliding microtome, stained in safranin and hematoxylin; mounted, and examined with a light microscope. A microprojector was used to measure the cell lumens. Clusters of earlywood and latewood tracheids were selected randomly for measurement of radial and tangential lumen diameters.

Tabulation of data revealed a significant relationship between the sap velocity profiles and the lumen area of the cells. The zone of maximum lumen area occurred 18-20 mm into the sapwood from the cambium. This zone corresponds to the previously-mentioned maximum sap velocity zone of

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15-20 mm. Smaller cell lumens were measured in the 0-5 mm region and at greater radial depths from the cambium.

Similar anatomical profiles were measured in trees of differing bole diameter as well as in trees growing in environments and areas other than the instrumented trees.

Relationship of Xylary Cell Structure to Sap Movement in Engelmann Spruce

Introduction

During recent years, research data has supported the hypothesis that water movement occurs primarily in the sapwood of a living tree (3,7). However, the precise cross-sectional area of the xylem involved in the conduction of water is a controversial issue among researchers. Various researchers (4,9) have stated that sap flow occurs in the outer rings of the sapwood. Their studies verify the findings of previous workers (2,11) relating the size of tracheid lumina to water transport. Bailey (1) states that a decrease in the size of the tracheids within the annual ring and within various regions of the sapwood hinders the upward conduction of water. Therefore it appears that the amount of water movement within the trees varies directly with the cross-sectional area of the tracheid lumens. More recently, Swanson (10) has measured the amount of sap movement within the cross-sectional area of the tree stem. His work established sap velocity profiles which indicate varied sap movement in areas measured inward from the cambium.

Swanson's study (10) was conducted at the Fraser Experimental Forest near Fraser, Colorado. Five Engelmann spruce trees were instrumented for measurement of sap velocities using the thermoelectric method. Velocity profiles for these trees show little sap movement in the outer 5 mm of the xylem. Sap flow reached a maximum velocity at 20 mm and then gradually decreased, leveling off at 30-35 mm. This very low rate of sap flow in the outer region of the sapwood is contrary to previous reports for coniferous trees (49). As suggested by Swanson (10), the band of tissue engaged in active conduction within the sapwood may be considerably

wider than previously reported.

This study is an attempt to correlate one quantitative anatomical characteristic of the xylary cells (the cross-sectional area of the tracheid lumen) with the sap velocity profiles as measured by Swanson (10).

Materials and Methods

One-half inch cores were removed from the instrumented trees at one-month intervals (May through August, 1967). The cores were all taken at approximately 4.5 feet above the ground and placed in test tubes of distilled water for refrigerated storage prior to laboratory processing. In the laboratory the growth increments were counted on the cores and related to radial depths within the tree. The cores were then divided into 5 mm blocks for sectioning. A sliding microtome was used to cut transverse sections 20 microns thick. The sections were double stained in haematoxylin and safranin and mounted directly from water. A micro-projector was used to enlarge the sections for measurement of the cell lumens. The following sampling and measuring techniques were employed:

1. Cells were selected from the middle growth increment of the section. For example, on a section showing five growth increments, a cluster of nine earlywood cells was selected randomly (three cells out from the edge of the fourth increment). Another group of nine cells was selected in the latewood of the same increment (three cells in from the second growth increment). Extremely small cells representing sections of the tapered ends of tracheids were excluded from measurement.

2. The cell lumens were measured radially and tangentially at their widest points.

   Core samples from trees other than those located at the Fraser Experimental Forest were also measured. These collections were made from trees near Pingree Park and on the Colorado State University campus. The purpose of this additional sampling was to determine if comparable cell lumen profiles occurred in trees growing in different environments.

Results and Discussion

The results of this study are expressed graphically by plotting the average cross-sectional area of the cell lumen and the sap velocity as reported by Swanson (10) versus the depth inward from the cambium of the tree. All of the cell lumen areas plotted are for the earlywood. There was no significant relationship observed in the cell lumen areas of the latewood when compared to distance from the cambium. Figure 1 depicts the relationship between the variables for a single tree. The maximum for both the cell lumen area and the sap velocity occurs at a depth of 20-25 mm. Samples taken from trees of different diameters (Figure 2) and from trees at different locations (Figure 3) show cell lumen area profiles similar to those of the instrumented trees.

There is considerable evidence to support the relationship between cell lumen area and sap velocity. Kozlowski (3) showed that for gymnosperms, the pattern of water movement upward involves a great portion of the sapwood. However, in gymnosperm seedlings it has been shown that the outer xylem ring may conduct less water than the other rings (6). Kozlowski (5) states that in the annual rings of gymnosperms, a preferential path of upward water movement has been identified in large diameter elements. He attributes this preference to the differences in the distribution and structure of bordered pits in the earlywood and latewood cells. Lundegardh (8) also found a preferential path of water movement in parts of annual rings of woody angiosperms and concluded that small xylem elements exerted a high transport resistance because of high capillary friction. Whatever the specific nature of the resistance in various tissues of woody plants, it appears that water tends to follow a path of least resistance in its ascent. Hence, the higher sap velocity in the zones of larger cell lumen area.

The depth at which the maximum cell lumen area occurs appears to be independent of the year and rate of growth (Table 1). Rather, it is directly related to the depth from the cambium. A search of the literature reveals no reference to such a phenomenon. However, the maximum sap velocity at 20-25 mm does not seem to be partially explained by the presence of large-lumened tracheids at this depth.

Another factor that will have considerable effect on the water conductance in conifers is the number, dimension, and condition of the bordered pits in the walls of adjacent sapwood tracheids. This relationship is now being studied under a National Science Foundation Grant.

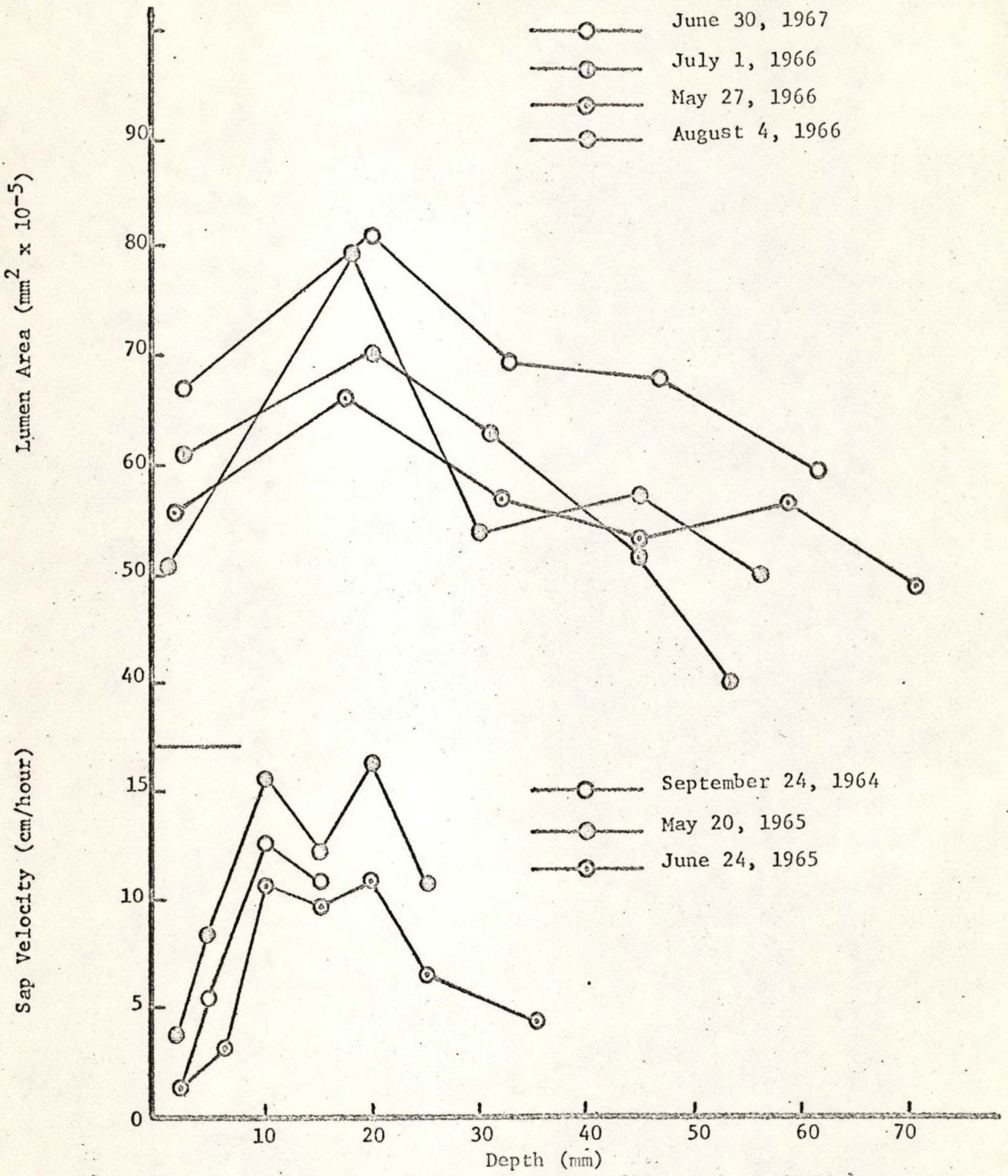

Fig. 1. Comparison of sap velocity profiles and tracheid lumen area in one Engelmann spruce tree. Measurements were taken on south side of tree (dbh = 9.5 inches).

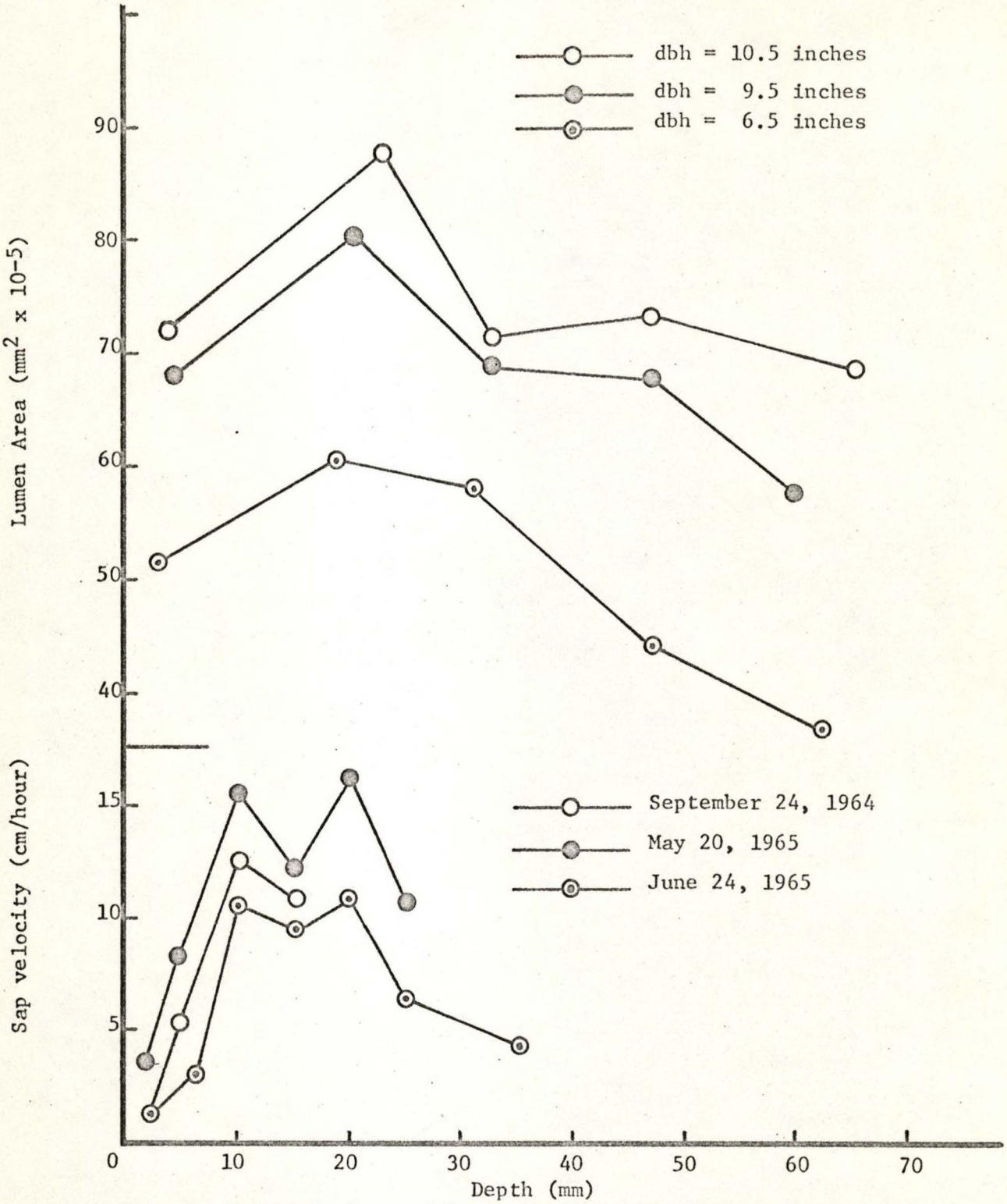

Fig. 2. Sap velocity and lumen area profiles from Engelmann spruce trees of differing bole diameter. Core samples were collected June 30, 1967.

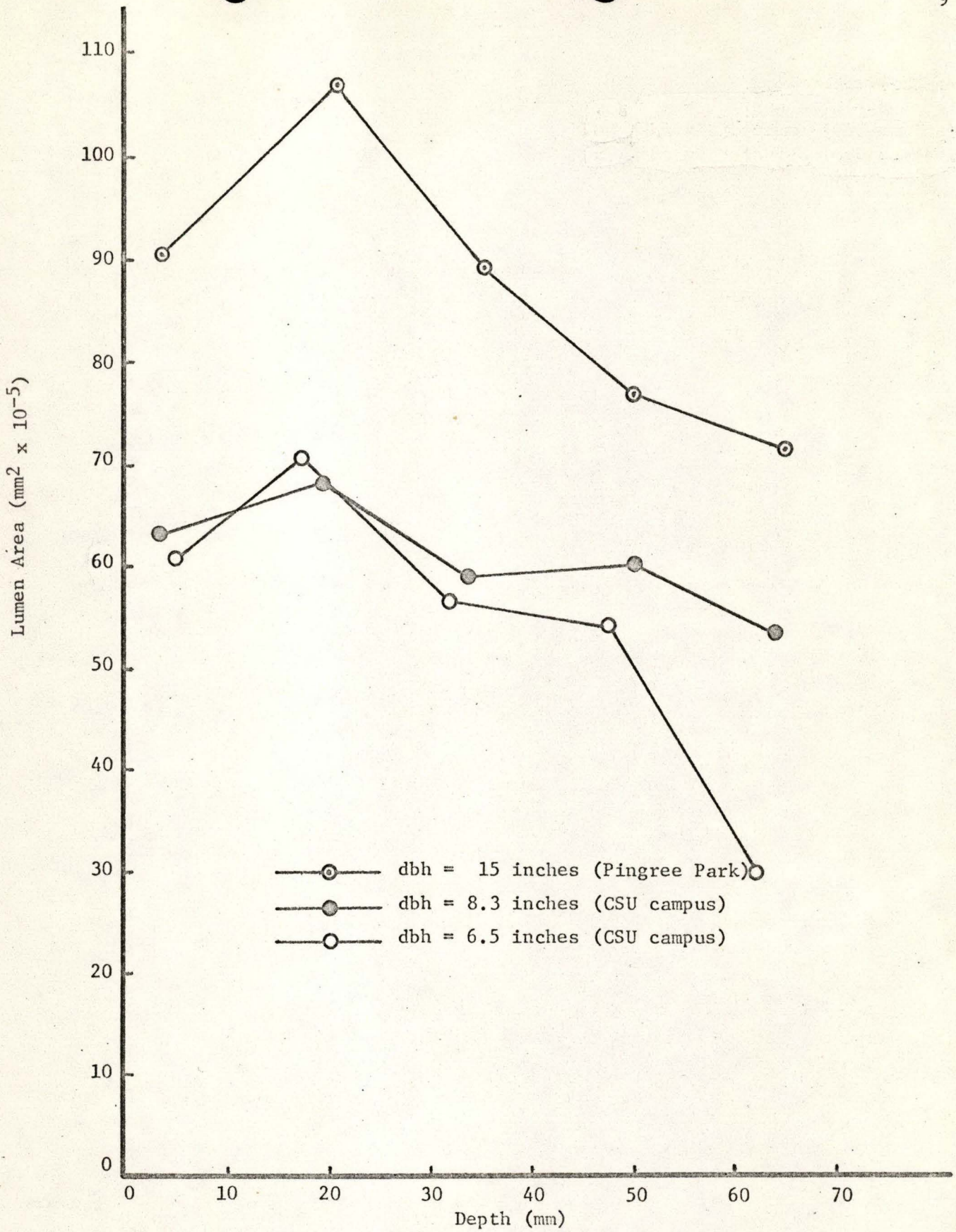

Fig. 3. Lumen area profiles from Engelmann spruce trees sampled from areas other than the Fraser Experimental Forest. Note similarity between these trees and those from Fraser.

Table 1. Comparing the annual growth rings of maximum lumen area among Engelmann spruce varying in stem diameter.

Tree	Diameter (breast height)	Maximum lumen area	Annual growth ring
A	6.5"	19 mm	18
B	9.5"	20 mm	17
C	10.5"	21.5 mm	15
D	15.0"	20.5 mm	6
E	8.3"	19.5 mm	10
F	6.5"	18.5 mm	11

Literature Cited

1. Bailey, I. W. 1958. The structure of tracheids in relation to the movement of liquids, suspensions, and undissolved gases. In "The Physiology of Forest Trees" (K. V. Thimann, ed.) 519-522. Ronald Press, New York.

2. Bailey, I. W. 1954. Evolution of the tracheary tissue of land plants. Contributions of Plant Anatomy. Chronica Botanica Company, Waltham, Massachusetts. 259 pp.

3. Kozlowski, T. T. 1961. The movement of water in trees. Forest Science 7 (2): 177-192.

4. Kozlowski, T. T. 1964. Water Metabolism in Plants. Harper and Row, New York. 227 pp.

5. Kozlowski, T. T. (ed.). 1968. Water Deficits and Plant Growth. Vol. 1. Development, Control, and Measurement. Academic Press, New York. 390 pp.

6. Kozlowski, T. T., Hughes, J. F., and Leyton, L. 1966. Patterns of water movement in dormant gymnosperm seedlings., Bioreology 3: 77-85.

7. Kramer, P. J. and Kozlowski, T. T. 1969. Physiology of Trees. McGraw-Hill, New York. 642 pp.

8. Lundegardh, H. 1954. The transport of water in wood. Arkiv. Botan. (2) 3 (6): 89.

9. Rudinsky, J. A. and Vite, J. P. 1959. Certain ecological and phylogenetic aspects of the pattern of water conduction in conifers. Forest Science 5 (3): 259-266.

10. Swanson, R. H. 1966. Seasonal course of transpiration of lodgepole pine and Engelmann spruce. Proceedings, International Symposium on Forest Hydrology. The Pennsylvania State University. 419-434.

11. Zahner, R. 1963. Internal moisture stress and wood formation in conifers. Forest Products Journal. 13 (6): 240-247.